Complete vehicle energy management with large horizon optimization

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1 Introduction

Hybrid vehicle technology has the premise of reducing fuel consumption under various driving conditions. This technology requires an energy management strategy to optimally control the power flow between the internal combustion engine (ICE) and the electric machine (EM), while meeting strict state-of-charge boundaries in the high-voltage battery. Besides an electric machine, heavy-duty vehicles can also be equipped with a refrigerated semi-trailer and many other auxiliaries with the interesting property of having a flexible power demand and/or the ability of storing energy (see Fig. 1). Including these components in the energy management strategy, yielding complete vehicle energy management (CVEM), is attractive for reducing fuel consumption, but requires a new approach to solving the energy management problem [1].

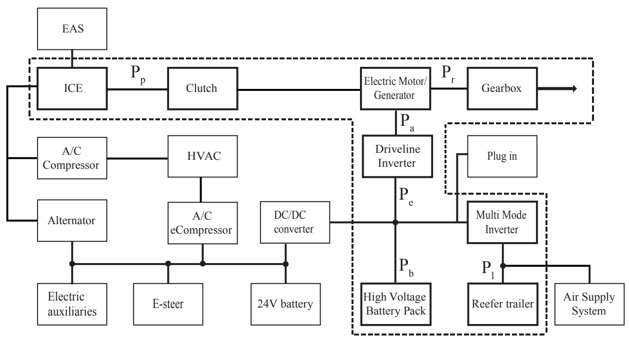

Figure 1: Topology of a hybrid heavy-duty vehicle

2 Approach

The approach taken in [1] is based on the dual decomposition. The CVEM problem is solved for a heavy-duty vehicle with an electric machine, a high-voltage battery and a refrigerated semi-trailer over a short horizon of 800 time steps. As long-haul heavy-duty vehicles easily operate for 10 hours and more, solving the problem for large horizons is necessary to truly establish the benefit of CVEM.
The dual decomposition results in four separated optimization problems, i.e., the dual functions. Each of the dual functions is related to one of the components in the vehicle and all dual functions are coupled by the dual variables. The primal problem is solved by iteratively solving the dual functions and subsequently updating the dual variables with a subgradient method. This approach is not only attractive because of its distributed nature, but also because of the decomposition, which allows each of the dual functions to be solved using any preferred solution method. By selecting the best solution method for each dual function, the decomposed CVEM problem introduced in [1] is solved for large horizons with 53000 time steps (approximately 15 hours).

3 Simulation results

The CVEM problem is solved using different solution methods for each of the dual problems. In particular, the solution of the dual function related to the engine and electric machine is found explicitly. The dual function related to the battery is solved with the Lagrangian method adapted to state constraints. The dual function related to the refrigerated semi-trailer is solved by applying 'the method of multipliers' similar to distributed quadratic programming. The results presented in Fig. 2 show that both, the battery State-of-Energy (SoE) and the temperature inside the refrigerated semi-trailer remain between bounds. Moreover, the computation time for this large-scale optimization problem is only 13.2 minutes on a standard laptop pc and scales linearly with the length of the horizon. In particular, computation time is reduced with a factor 100 for a horizon with 2000 time steps, compared to the approach taken in [1].

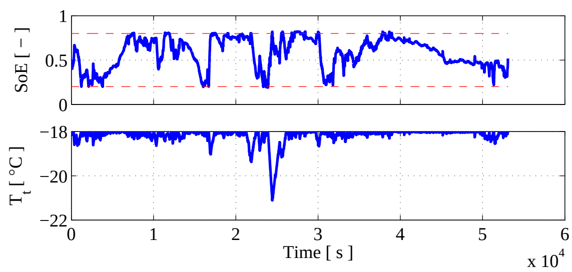

Figure 2: Optimal State-of-Energy and temperature trajectory

4 Acknowledgements

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References

[1] T.C.J. Romijn, M.C.F. Donkers, J.T.B.A. Kessels and S. Weiland, *A Dual Decomposition Approach to Complete Energy Management for a Heavy-Duty Vehicle,* Proc. 53rd Annu. Conf. on Decision and Control, 2014.